# PROJECT DATA

## Sonsight, Inc. - 02GO12066

### Visible Spectrum Incandescent Selective Emitter

| | | | |
|---|---|---|---|
| Recipient: | Sonsight, Inc. | Instrument Number: | DE-FG36-02GO12066 |
| Recipient Project Director: | Devon R. McIntosh 301.283.6250<br>17609 Clinton Dr.<br>Accokeek, MD 20607 | CPS Number: | 1838 |
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| Recipient Type: | Individual | GO Contract Specialist: | Melissa Wise 303.275.4909 |
| Subcontractor(s): | | B&R Number(s): | ED190602 |
| | | PES Number(s): | 02-2140, 03-11015 |
| EERE Program: | Building Technologies | State Congressional District | MD - 5 |

**PROJECT SCOPE:** The objective of this project is to design, build, and test a prototype unit of a novel light source that utilizes incandescence with an efficiency and longevity comparable to that of fluorescent lighting. The 18 month project will develop a novel heating arrangement to attain and maintain high, stable incandescent temperatures, and optically and physically optimize the composite ceramic oxide emitter. Energy efficiency is calculated to be roughly three times that of standard incandescent bulbs. This is a yearly energy savings of .67 x 1011 kWh, which is 2.3 x1014 Btu, and which translates to a cost savings of over $6.7 billion per year.

**FINANCIAL ASSISTANCE**

| | | | |
|---|---|---|---|
| Approved DOE Budget | $200,000 | Approved DOE Share | $200,000 |
| Obligated DOE Funds | $200,000 | Cost Share | $5,000 |
| Remaining Obligation | $0 | | |
| Unpaid Balance | $11,114 | **TOTAL PROJECT** | **$205,000** |

Project Period: 8/1/02-1/31/04

# TECHNICAL PERFORMANCE
## DE-FG36-02GO12066
## Sonsight, Inc.
## Visible Spectrum Incandescent Selective Emitter

## PROJECT SYNOPSIS

The objective of this project is to design, build and test a prototype unit of a novel light source over an 18 month period. The invention is a new type of light source that utilizes incandescence with an efficiency and longevity comparable to that of fluorescent lighting. Efficiency is obtained by tuning the material parameters affecting radiative transfer within a ceramic oxide composition to allow significant selective emissivity within the visible spectrum.
The proposed work is directed at: (1) developing a novel heating arrangement to attain and maintain high, stable incandescent temperatures, and (2) optically and physically optimizing the composite ceramic oxide emitter such that when heated to high operating temperature, it emits, within the infrared, a much smaller portion of its total radiated power than that emitted by state-of-the-art incandescent bulbs.

Questions to be answered during the work include the following.

(1) What maximum VIS/NIR radiant power and emissivity ratios can be attained at 2650 K?
(2) What electronic switching configuration is most advantageous for use with the ballast/heater coil?
(3) What are the actual observed lifetimes and electrode performance of molybdenum electrodes?
(4) What is the observed emitter body life and how does its performance vary with time?
(5) What are the design tradeoffs for an internally mounted heating coil that must be large enough to heat effectively yet be so mounted as to preclude physical contact with the emitter body?
(6) What are the optimum refractory oxide volume fractions for high temperature operation?
(7) How accurately can Sonsight measure the emitter body temperature, the spectral intensity emissivity distribution of which is highly nonlinear?
(8) What are the quantitative improvements to be had from utilizing a bi-layer emitter body with a low emissivity inner layer and a partially transmissive outer layer?
(9) What are the tradeoffs associated with various mounting approaches of the emitter within the glass bulb?
(10) What is the improved estimate of manufacturing costs?

A number of energy, economic and environmental benefits are expected, such as less energy use and cost, reduced $CO_2$ emissions, no mercury contamination, and a healthier and more productive optical/visual environment. The energy efficiency of the proposed invention is calculated to be roughly three times that of standard incandescent light bulbs. This is a yearly energy savings of $.67 \times 10^{11}$ kWh, which is $2.3 \times 10^{14}$ Btu, and which translates to a cost savings of over $6.7 billion per year.

## SUMMARY OF TECHNICAL PROGRESS

The project is complete and the final report was submitted and accepted in March 2004. All DOE funds were costed and the cost share was met. The first research goal was achieved in that a novel heating arrangement to attain and maintain high, stable, incandescent temperatures was demonstrated; however, the second research goal of attaining, within the IR, high emitter operating temperatures, a much smaller portion of total radiated power than that emitted by state-of-the-art incandescent bulbs, was not met. As a result, several directly related objectives downstream of this goal were also not achieved. Namely, determining the electronic switching configuration most advantageous for use with the ballast/heater coil, determining the tradeoff associated with various mounting approaches of the emitter within the glass bulb, and obtaining an improved estimate of manufacturing costs were not achieved. Instead, much time was spent pursuing alternatives for obtaining improved emitter efficiencies. The alternatives investigated include the following:

1. Utilization of rare earth oxide powders as optically selective components for improving spectral selectivity.
2. Fabrication of thin mono-layer emitter rods for possible use as optically thin emitters to eliminate dependence on large optical scattering for improved emitter efficiency.
3. Fabrication of emitter bi-layer rods with an optically thin emitter layer mounted on a substrate core.

## SUMMARY OF PLANNED WORK

The project is complete and there is no follow-on work proposed.

## PROJECT ANALYSIS

There were positive and negative results from this investigation. The first is that, with the investigated approaches, the maximum sustained emitter efficiencies are about 1.5 times that of a standard incandescent bulb. This is a positive attribute, but it does not appear sufficient to overcome higher cost (i.e. up to five times that of the standard bulb) and ensure commercial success. A negative observed characteristic of the emitter was significant grain growth soon after attaining operating temperatures. This is an undesirable characteristic that results in substantially less optical scattering and spectral selectivity, and which significantly limits emitter efficiencies to the values reported. In summation, the negatives out weight the positives and additional work is required, but not planned at this time.

## ACTION REQUIRED BY DOE HEADQUARTERS

No action is required from DOE Headquarters at this time.

# STATEMENT OF WORK
## DE-FG36-02GO12066
## Sonsight, Inc.
## Visible Spectrum Indandescent Selective Emitter

## Detailed Task Description

### Task 1: Determine Baseline Efficiency at 2650 K & Optimize High Temp. Microstructure and Volume Fractions

Baseline VIS/NIR radiant power and emissivity ratios at 2650 K will be determined utilizing a simple experimental configuration: a Nernst glower powered by a constant current power supply (to prevent thermal runaway), and structured to have the MESE's emissivity, and prepared with thermally insulated ends. Sonsight has been routinely fabricating spectrally enhanced Nernst glower by extruding the thin filament rods from the same powder composition as the MESE. Significant optical scattering is introduced by including micron grain size graphite powder and carbon black within the ceramic powder composition. During subsequent high temperature sintering of the extruded rods, the carbon black and graphite powder vaporize within the furnace, leaving many small individual micro-pores, which serve as optical scattering centers. Platinum wire electrodes are subsequently attached to both ends. A propane flame is used to initially heat the emitter and attain its turn-on temperature, after which a 1 - 10 mT vacuum is applied within a bell jar (air operation is possible but vacuum operation is more stable). To date, operating temperatures of our Nernst glowers have been limited to about 2050 K by thermal failure of the electrodes enough platinum was unavailable to ensure "cool" ends. However, in the proposed project, to achieve 2650 K with the minimum amount of platinum, the emitter's ends will be thermally insulated before attaching the electrodes. A tube extruder will be utilized to form short, ring-like tubes from the emitter body's ceramic material (zirconia has very low thermal conductivity), which will be placed in close contact over the ends of the emitter body and cemented on. The electrodes will be attached to these end tubes. To improve both radiative temperature measurements and spectral characterization, the radiated spectrum at 2650 K will be measured for $\lambda$ = .4 – 2.5 $\mu$m. While varying much less with temperature than the Plank function, the spectral absorptivity does vary with temperature (see for example Griffiths et al., 1976, and Cox et al., 1986). The resulting emissivities will necessarily change because the proposed emitter will operate much hotter than the MESE. As was done for the MESE, Sonsight expects to determine the most appropriate ceramic composition by iterative steps that include numerical calculations, compositional adjustments, and optical measurements. Also, electron microscopy and ultrasound analyses, available through the Technology Access Program (TAP) at the University of Maryland, will be used to facilitate adjustments to the porosity microstructure of the emitter body and therefore to its optical scattering. The VIS/NIR radiant power and emissivity ratios are directly determined by the relative magnitudes of the spectral absorptivity and the optical scattering.

### Task 2: Fabricate Baseline Emitter With Tungsten Coil Ballast/Heater and Characterize Emitter Stability

To study emitter stability and initial radiant heating, Sonsight will fabricate and mount Nernst glowers (i.e. the baseline emitter) with platinum electrodes within external heating coils within an evacuated (i.e. 1 mT) bell jar. As before, end tubes will act as thermal insulation between the electrodes and the doped zirconia filament. Sonsight will simultaneously measure current and radiated spectral intensity while varying the incident radiant power (via input power adjustments to the external heating coils) and the applied voltage. For a wide range of incident radiant powers, experimental curves can then be calculated for the temperature dependence of such parameters as voltage, resistivity, emissivity, and total input power. These measurements will help characterize emitter stability and calculate optimal input parameters.

## Task 3: Fabricate and Characterize Baseline Emitter With Molybdenum Electrodes

To demonstrate the suitability of molybdenum electrodes, Sonsight will fabricate and mount Nernst glowers within external heating coils within an evacuated (i.e. 1 mT) bell jar. This time molybdenum electrodes will be used. As before, end tubes will act as thermal insulation between the electrodes and the doped zirconia filament. Oxygen partial pressure monitoring will help determine any notable rates of electrolysis, allowing comparisons of the electrochemical performance of the two electrodes. Depending on the results, Sonsight may also investigate molybdenum-platinum and molybdenum-tungsten alloys as well.

## Task 4: Fabricate and Characterize Single-Layer Tubular Emitter

For the MESE, the bi-layer cylindrical body was fabricated by isostatic pressing. However, unlike the extruded Nernst glowers, such bodies did not electrically conduct even when heated well past typical “turn-on” temperatures. Sonsight will therefore form Nernst glowers in the form of hollow tubes by extrusion (this is essentially the proposed emitter minus the internally mounted heating coil), insulate their ends with close-fitting end-tubes that are compositionally similar to the emitter body, mount them within external heating coils, and as before, obtain experimental curves of the various temperature and spectral intensity dependencies over a range of incident radiant and electrical powers. Physical parameters such as the wall thickness and length of the tubes will be varied to determine performance dependencies and structural limitations.

## Task 5: Fabricate and Characterize Double-Layer Tubular Emitter

This task is similar to Task 4 except to enhance the VIS/NIR emissivity ratio, a double-layer emitter body with a low emissivity inner layer and a thin, partially transparent outer layer will be extruded with a modified extruder insert.

## Task 6: Construct Emitter With Internally Mounted Ballast/Heater and Electronic Switching

The ballast/heating coil will be mounted internally within the emitter body. To reduce sagging when hot, the coil will be of specially processed, closely wound tungsten, similar to that used in halogen bulbs. It will be arranged, while elongated, within a mount that maintains the elongation while preventing electrical conduction between the coil and the emitter body. A bi-lateral diode/triode switch will be arranged between the coil and the emitter body so as to interrupt direct connection of the coil across the supply voltage and yield a series connection with the emitter body when electrical conduction ensues. The component parameters will be optimized to provide the most stable and efficient performance.

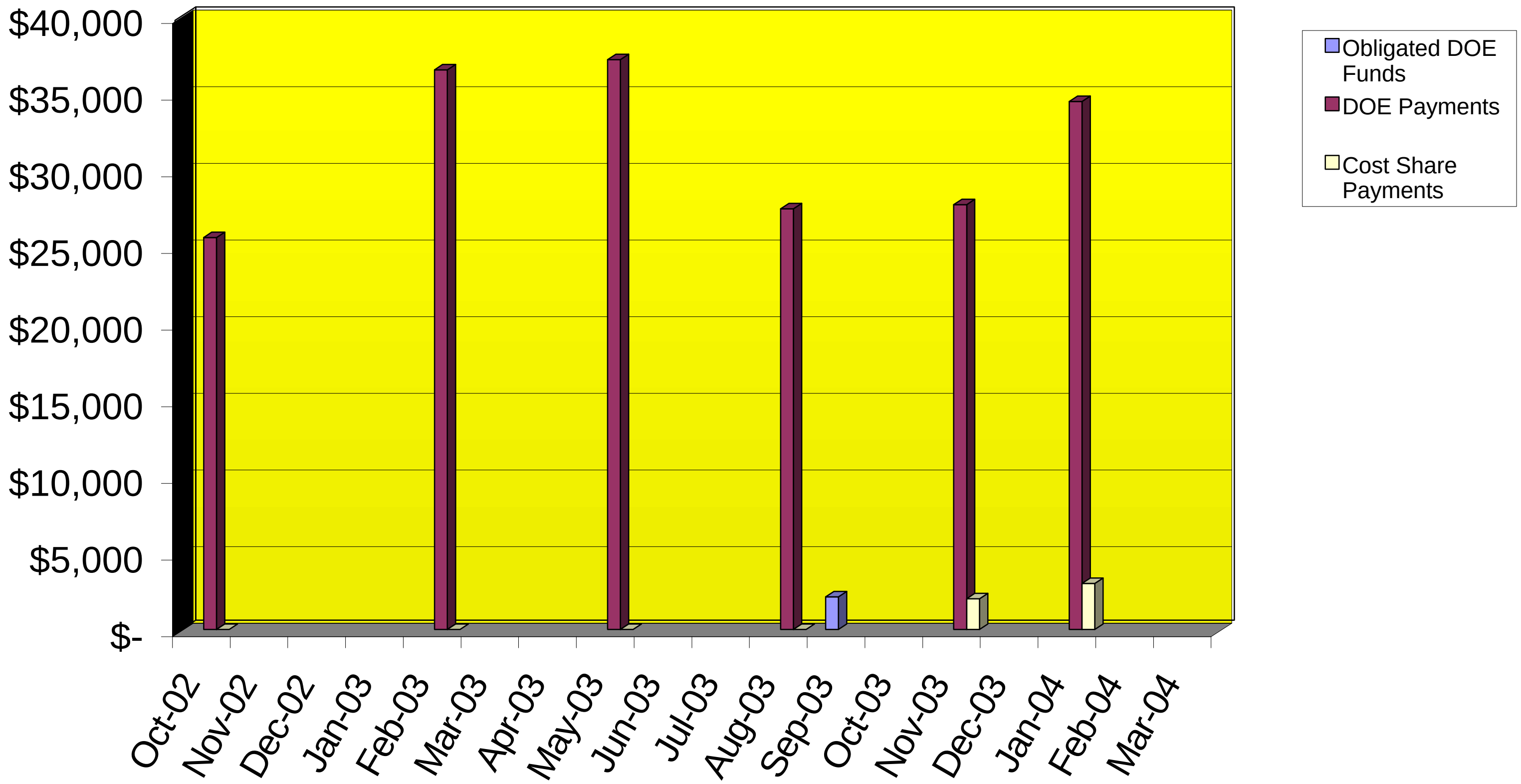
## Task 7: Mount Emitter Within Bulb and Fine-tune Enclosed Performance

This task includes designing and fabricating the emitter mount, mounting and testing the emitter within the bulb, and finally, via measurements and calculations, fine-tuning the performance of the enclosed emitter. A thoroughly tested and characterized prototype is the objective.

## Project Cost Performance in DOE Dollars for Fiscal Year 2003

**DE-FG36-02GO12066 Sonsight, Inc.**

**Visible Spectrum Incandescent Selective Emitter**




| | Oct-02 | Nov-02 | Dec-02 | Jan-03 | Feb-03 | Mar-03 | Apr-03 | May-03 | Jun-03 | Jul-03 | Aug-03 | Sep-03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Obligated DOE Funds | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $2,124 |
| DOE Payment | $25,566 | $0 | $0 | $0 | $36,514 | $0 | $0 | $37,178 | $0 | $0 | $27,451 | $0 |
| Cost Share Payment | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |

| | Oct-03 | Nov-03 | Dec-03 | Jan-04 | Feb-04 | Mar-04 | PFY* | Cumulative |
|---|---|---|---|---|---|---|---|---|
| Obligated DOE Funds | $0 | $0 | $0 | $0 | $0 | $0 | $197,876 | $200,000 |
| DOE Payment | $0 | $27,724 | $0 | $34,452 | $0 | $0 | $0 | $188,886 |
| Cost Share Payment | $0 | $2,000 | $0 | $3,000 | $0 | $0 | $0 | $5,000 |

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|---|---|
| Approved DOE Budget: | $200,000 |
| Approved Cost Share Budget: | $5,000 |
| Total Project Budget: | $205,000 |

* Prior Fiscal Years

# Sonsight - 02GO12066

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | Determine Baseline Efficiencies at Target Temp. & Optimize High | Thu 8/1/02 | Fri 12/5/03 |
| 2 | Fabricate Baseline Emitter With Tungsten Coil Component and | Fri 1/31/03 | Tue 6/3/03 |
| 3 | Fabricate Baseline Configuration With Target Heat Supply | Mon 3/31/03 | Fri 8/29/03 |
| 4 | Fabricate Single-Layer Emitter Body and Characterize | Fri 5/30/03 | Tue 9/30/03 |
| 5 | Fabricate Double-Layer Emitter Body and Characterize | Mon 7/7/03 | Fri 11/28/03 |
| 6 | Construct Emitter With Electrical and Internally Mounted Components | Mon 7/7/03 | Thu 10/30/03 |
| 7 | Mount Emitter Within Bulb and Fine-tune Enclosed Performance | Mon 7/7/03 | Fri 11/28/03 |
| 8 | Project Management and Reporting | Thu 8/1/02 | Fri 1/30/04 |